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Relative Ignition Propensity of Test Market Cigarettes

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ABSTRACT

The Federal Trade Commission (FTC) staff requested that the National Institute of Standards and Technology (NIST) conduct tests to determine whether a test market cigarette made with a slower burning paper would reduce the risk that such a cigarette, if dropped or discarded, would start a fire. While NIST does not routinely perform product tests, it agreed to do so in this case, recognizing the important role of the FTC in assuring the public of the veracity of product claims and the high potential for less fire-prone cigarettes to reduce fire deaths and injuries. NIST staff purchased conventional and modified cigarettes from the test market and measured the relative ignition propensities of the two cigarette types using the Mock-up Ignition Test Method and the Cigarette Extinction Test Method, both developed under the Fire Safe Cigarette Act of 1990. Analysis of the test data shows that the modified cigarette has a lower relative ignition propensity than the conventional cigarette.

Keywords: fire, cigarette, ignition

THE RESEARCH ON REDUCED IGNITION PROPENSITY CIGARETTES CONDUCTED BY NIST SINCE 1984 WAS DONE IN THE INTEREST OF SAVING LIVES AND PROPERTY FROM CIGARETTE-INDUCED FIRES. IN NO WAY DOES IT LESSEN OR NEGATE THE HEALTH HAZARDS AND ADDICTIVE NATURE OF SMOKING AS DETERMINED BY THE SURGEON GENERAL OR SUGGEST THAT NIST AND THE DEPARTMENT OF COMMERCE CONDONE SMOKING.

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I. INTRODUCTION

Cigarettes dropped onto upholstered furniture and beds continue to be the leading single cause of fire deaths in the United States. The Consumer Product Safety Commission (CPSC) estimated that in 1997, cigarette-ignited fires resulted in about 880 deaths, 2120 injuries, and a direct property loss of $335 million.[1] A 1993 report had estimated the total cost to our society of $5 billion.[2]

Over the past three decades, most of the fire safety standards effort has been directed at improving the resistance of the fuel (mattresses[3], commercial furniture[4], and residential upholstered furniture[5]) to the ignition source. These standards have contributed to reducing these losses significantly.[6] However, the median life of these furnishings has been estimated at 12 years for mattresses and 15 years for upholstered furniture[7], so most of the old items have been replaced, and little additional decrease in fire losses is expected from these standards.

There have also been efforts to reduce the potency of the ignition source, the cigarette, by reducing its propensity to ignite soft furnishings. Research under two Federal Acts, each of three-year duration, has generated substantial technology in this direction:

> **The Cigarette Safety Act of 1984 (P.L. 98-567).** Research showed that there were three modifications of the cigarette that would reduce its likelihood of starting a fire: reduced tobacco packing density, smaller cigarette circumference, and less porous paper.[8] A shorter tobacco column length, the absence of a filter tip, and the absence of a burn additive in the paper had effects in limited cases.
>
> In addition, five patented modifications were tested. All five showed significantly reduced ignition propensity relative to identical cigarettes without the patented feature.[8]

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[1] Mah, J., Smith, L., and Ault, K., "1997 Residential fire Loss Estimates," U.S. Consumer Product Safety Commission, 2000.

[2] Ray, D.R., Zamula, W.W., Miller, T.R., Cohen, M.A., Douglass, J.B., Galbraith, M.S., Lestine, D.C., Nelkin, V.S., Pindus, N.M., Smith-Regojo, P., "Societal Costs of Cigarette Fires," Report No. 6, Technical Advisory Group, Fire Safe Cigarette Act of 1990, U.S. Consumer Product Safety Commission, August 1993.

[3] 16 CFR 1632.

[4] Based on "E 1352 Standard Test Method for Cigarette Ignition Resistance of Mock-up Upholstered Furniture Assemblies," Annual Book of ASTM Standards, Vol. 4.07, ASTM, Philadelphia, PA.

[5] Based on "E 1353 Standard Test Method for Cigarette Ignition Resistance of Components of Upholstered Furniture," Annual Book of ASTM Standards, Vol. 4.07, ASTM, Philadelphia, PA.

[6] Comparison of data in the CPSC National Fire Loss Estimates for 1984 and 1997 shows a 40% reduction in deaths and injuries.

[7] Private communication, M. Neily, U.S. Consumer Product Safety Commission, 2000.

[8] Gann, R.G., Harris, Jr., R.H., Krasny, J.F., Levine, R.S., Mitler, H.E., and Ohlemiller, T.J., *The Effect of Cigarette Characteristics on the Ignition of Soft Furnishings,* Report No. 3, Technical Study Group on Cigarette and Little Cigar Fire Safety, Cigarette Safety Act of 1984, and NBS Technical Note 1241, U.S. National Bureau of Standards, Gaithersburg, MD, 1987.

The Fire Safe Cigarette Act of 1990 (P.L. 101-352). Among other products, this Act resulted in:

- Two methods for measuring the ignition propensity of a cigarette type.[9]
    - The Mock-up Ignition Method measures whether a cigarette causes ignition by transferring enough heat to a fabric/foam simulation of a piece of furniture (substrate). A lit cigarette is placed on one of three different mock-ups. Ignition (failure) is defined as the char propagating 10 mm away from the tobacco column. The procedure is repeated a set number of times and the percent of failures is calculated.
    - The Cigarette Extinction Method measures whether a cigarette, when placed on a heat-absorbing substrate, burns long and strong enough to cause ignition had it been dropped on a piece of furniture. A lit cigarette is placed on one of three substrates consisting of a fixed number of pieces of common filter paper. Failure is defined as the cigarette burning its full length. The procedure is repeated a set number of times and the percent failures is calculated. [While the metric in this test is the cessation of burning, it is not a test for "self-extinguishing" cigarettes. Some cigarette designs that pass this procedure have also performed well in the Mock-up Test, burning their full length without causing an ignition.]

  The two methods produce similar results. Both were subjected to an interlaboratory evaluation (ILE) to measure their reproducibility. In addition, NIST tested 20 commercial cigarettes and 5 experimental cigarettes using the two methods.
- A cigarette smoke toxicity testing plan.[10] A panel of experts from government, industry and academia developed a four-tier plan, proceeding from rapid and inexpensive tests to longer, more costly measurements.
- Estimation of the societal costs of cigarette fires.[2]

Efforts to develop a Federal standard for less fire-prone cigarettes have been unsuccessful. In June of this year, the State of New York became the first jurisdiction to enact such legislation. Other states are considering similar action.

On January 11, 2000, a major manufacturer of cigarettes announced that it would soon be test marketing a modification of one of their cigarettes that would make them less likely to start a fire. Having evolved from one of the patented ideas tested under the Cigarette Safety Act of 1984, the modification entails adding circumferential bands of low air permeability paper to the paper that wraps the tobacco column. These bands were said to reduce the rate of burning, making it more difficult for the cigarette to heat furnishings and cause ignition.

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[9] Ohlemiller, T.J., Villa, K.M., Braun, E., Eberhardt, K.R., Harris, Jr., R.H., Lawson, J.R., and Gann, R.G., *Test Methods for Quantifying the Propensity of Cigarettes to Ignite Soft Furnishings,* NIST Special Publication 851, National Institute of Standards and Technology, 1993.

[10] Lee, B.C., Mishra, L.C., Burns, D.M., Gairola, C.G., Harris, J.E., Hoffman, D., Pillsbury, Jr., H.C., and Shopland, D.R., "Toxicity Testing Plan," Report No. 5, Technical Advisory Group, Fire Safe Cigarette Act of 1990, U.S. Consumer Product Safety Commission, August 1993.

On May 15, 2000, soon after the test marketing of the modified cigarettes began, Joan Z. Bernstein, Director of the Federal Trade Commission (FTC) Bureau of Consumer Protection, sent a letter to Dr. Jack E. Snell, Director of the National Institute of Standards and Technology (NIST) Building and Fire Research Laboratory (BFRL), requesting that NIST "conduct tests to determine whether and to what extent this cigarette does reduce the risk of ignition." On May 19, 2000, Dr. Snell replied "While NIST does not routinely perform product tests, we recognize the important role of the Federal Trade Commission in assuring the public of the veracity of product claims and the high potential for less fire-prone cigarettes to reduce fire deaths and injuries. We thus agree to measure the ignition propensity of these test cigarettes relative to the performance of the unmodified product. Note that this is not an absolute measure of ignition probability in real circumstances, but is a strong indicator as to whether a reduction in cigarette-initiated fires might be expected." Copies of the two letters appear as Appendices A and B to this report.

This report presents the results of the NIST testing of the ignition performance of the conventional cigarettes and the modified (banded) product. While the only publicly stated difference between the two types was the banding of the wrapping paper, NIST performed no tests to ascertain that there were not additional differences.

II. WORK PLAN

Three sets of measurements were carried out. These are described in reverse order of their execution to clarify the rationale for each component of the project.

A. *Tests to determine the extent of difference in ignition propensity between the conventional and modified cigarettes.* Both the Mock-up Ignition Method and the Cigarette Extinction Method were used. The apparatus and procedures, given in Appendices C and D, respectively, are the same as those used in the 1993 study.[9] In each case, a sufficient number of repetitions were performed to ensure that we could see real changes, yet few enough to produce results in a timely manner.

B. *Tests to help estimate the impact of the modified cigarettes.* Doing this required placing the results in the context of the extensive testing on experimental and commercial cigarettes performed under the two Acts.

   1. This task was to "calibrate" the mock-up substrates relative to those used in the 1993 testing. This involved using two experimental cigarettes of different ignition strengths (types 529 and 531 from the 1990 Act[9]) and determining the extent to which the new substrates performed as their 1993 counterparts did.
   2. This "calibration" required knowing that the extent to which the two experimental cigarette types showed the same ignition strength as in 1993. (They had been stored in freezers since then.) For this, the two were checked against each of two filter paper substrates for which data had been taken in 1993. This filter paper is invariant over the years.

III. MATERIALS AND METHODOLOGY

A. Cigarettes

1. **Experimental Cigarettes.** A supply of the experimental cigarettes provided by the cigarette industry during the course of the Fire Safe Cigarette Act of 1990 had been stored in freezers at approximately 0 °C since that time. Two were selected for this project:[9]

   - Cigarette 529 was 100 mm in length and 25 mm in circumference, manufactured of expanded, flue-cured tobacco, and wrapped in paper of low air permeability.
   - Cigarette 531 was also 100 mm in length and 25 mm in circumference and manufactured of expanded, flue-cured tobacco. The tobacco was wrapped with paper of conventional air permeability.

2. **Commercial Cigarettes.** Cartons of the test cigarettes with the banded paper were purchased in Denver, CO (one of the test market cities) in May 2000. Cartons of conventional cigarettes of the same brand were purchased at a different location on the same date in the same city. The cigarettes[11] were characterized as follows:

   Weight: Both the conventional and modified cigarettes weighed 1.030 g each.

   Band structure: The band dimensions were determined to provide an approximate characterization for identification of these cigarettes. The bands were approximately 6 mm in width and were spaced by about 20 mm. Details are provided in Appendix E. Neither the porosity nor the air permeability of the paper or the bands was measured.

   No further chemical or physical measurements were performed on either set of cigarettes. Thus, it is not known whether there were any additional differences between the conventional and modified packings.

B. Substrate Materials

1. **Fabrics.** The #4, #6, and #10 cotton ducks used in this study were taken from stock remaining from the 1993 ILE conducted by NIST.[9] Since 1993, the ducks have been stored at NIST in a conditioning room, nominally at a relative humidity of 50 ± 5 % and a temperature of 21 °C ± 3 °C.

   Cigarette industry studies[12,13] had shown that some fabrics produced reversals in the ordering of cigarette ignition performance. These reversals were said to be more likely with fabric areal densities in the range 0.30 kg/m^2 to 0.44 kg/m^2 (9 oz/yd^2 to 13 oz/yd^2).

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[11] Both types of cigarettes were Merit Ultra Light 100s. Certain commercial materials and products are identified in this report to specify the procedures adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology.

[12] Spears, A.W., Rhyne, A.L., and Norman, V., "Factors for Consideration in a Test for Cigarette Ignition Propensity on Soft Furnishings," *J. Fire Sciences* **13**, 59-83 (1995).

[13] Lewis, L.S., Morton, M.J., Norman, V., Ihrig, A.M., and Rhyne, A.L., "The Effects of Upholstery Fabric Properties on Fabric Ignitabilities by Smoldering Cigarettes. II.," *J. Fire Sciences* **13**, 445-471 (1995).

We designed the current study to include one or more such fabrics to determine whether the relative performance of the conventional and banded cigarettes might reverse. Canvassing the local fabric/upholstery stores, we purchased 19 100 % cotton fabrics in this weight range. Each showed smoldering afterglow when ignited with a small flame from a propane torch and then blown out. However, only one of these then supported smoldering ignition from a cigarette. This material had an ivory color and an areal density of 0.36 kg/m^2 (10.5 oz/yd^2). We purchased a continuous length from a single bolt of this fabric for use in this study.

2. **Foam.** Non-fire-retarded flexible polyurethane foam has become a specialty item not routinely stocked by vendors. Owing to a lack of inventory, the manufacturer of the non-fire-retarded polyurethane flexible foam used in the 1993 standard mock-up tests (no. 2048 from Vitafoam Inc., High Point, NC) could not supply material for the present study within the available time frame. We learned that Philip Morris U.S.A. had on hand a supply of the 200 mm x 200 mm x 50 mm foam blocks. NIST purchased from Philip Morris 1000 pieces of that non-fire-retarded foam for the present study. An essential component of the test plan (Section III.E) is a determination of whether the substrates using this new foam perform the same as the 1993 substrates. A successful comparison would both enable comparison of the new data with the 1993 results and quell any concerns about the source of the new foam blocks. The test results reported in Section IV.B. of this report show there was no difference in ignitability between the substrates made with the new foam and the corresponding substrates in the 1993 study.

3. **Film.** The polyethylene film used with the #4 cotton duck substrates in this study was taken from stock left over from the 1993 ILE.[9] Since 1993, the roll of film has been stored at NIST in its original cardboard shipping box.

4. **Filter Paper.** The paper used was 150 mm diameter Whatman #2 filter paper that was taken from stock remaining from the 1993 ILE.[9] Since 1993, the paper has been stored at NIST in the original sealed boxes containing 100 papers each.

C. General Test Procedure

Four test chambers were employed in executing each method. A ***test point*** is defined as an evaluation of a specific cigarette/substrate/procedure combination. Each test point was evaluated simultaneously in the four test chambers. These four simultaneous test point determinations are called a ***test set***. A ***test cycle*** is the combination of all possible test points (performed in consecutive test sets) in a randomized sequence.

C. Verification of the Ignition Propensities of Experimental Cigarettes

A series of tests was performed to determine whether the ignition propensities of cigarettes 529 and 531 had remained unchanged since 1993. For the sake of time, each cigarette was tested on only two of the original filter paper substrates: 3 and 10 layers for cigarette 529, 10 and 15 layers for cigarette 531. Cigarettes from four packs were randomized and an identification number was printed in pencil on the filter tip of each cigarette. Six test sets were performed for each test point, resulting in 24 repetitions per test point. The results were to be compared with the NIST results from the 1993 interlaboratory evaluation (ILE) of the two test methods.

The randomized sequence of tests was:

Cycle	Test Point			
1	1	2	4	3
2	1	3	2	4
3	3	1	4	2
4	4	1	3	2
5	3	1	2	4
6	1	2	3	4

where the test points were:

Test Point	Cigarette	Test Type	# Layers
1	529	Extinction	3
2	529	Extinction	10
3	531	Extinction	10
4	531	Extinction	15

E. Evaluation of the Susceptibility of the Foam/Fabric Film Substrates

A second series of tests was performed to determine the degree of similarity of the new substrates (consisting of long-stored fabrics and film and a different batch of foam) to those in the 1993 ILE. Two substrates were tested using the two experimental cigarettes: the #10 and # 6 cotton duck substrates were tested with cigarette 529, the #6 and #4 cotton duck substrates were tested with cigarette 531. In addition to the randomization of the cigarettes, the pieces of foam, fabric and film were also randomized and labeled. Six test sets were performed for each test point, resulting in 24 repetitions per test point. The results were again to be compared with the NIST results from the 1993 ILE. The randomized sequence of tests was:

Cycle	Test Point			
1	2	4	1	3
2	1	2	4	3
3	2	1	4	3
4	4	2	1	3
5	4	3	2	1
6	2	3	4	1

where the test points were:

Test Point	Cigarette	Test Type	Duck #
1	529	Mockup	6
2	529	Mockup	10
3	531	Mockup	4
4	531	Mockup	6

F. Evaluation of the Relative Ignition Propensities of the Banded Cigarettes

A third series of tests was performed to determine the relative ignition propensities of the conventional and banded cigarettes. Both were tested using the two test methods. For the Mock-up Ignition Test, additional testing was performed with a substrate consisting of the ivory cotton fabric and the standard polyurethane foam. All component materials were randomized and labeled. Eight test sets were performed for the fabric substrates, six test sets for the filter paper substrates. The randomized sequence of Cigarette Extinction Test Method testing was:

Cycle	Test Point					
1	6	4	5	2	1	3
2	1	3	5	4	6	2
3	2	1	5	4	3	6
4	5	6	1	2	3	4
5	5	2	3	6	4	1
6	5	4	6	2	1	3

where the test points were:

Test Point	Cigarette	# Layers
1	Conventional	3
2	Conventional	10
3	Conventional	15
4	Banded	3
5	Banded	10
6	Banded	15

The randomized sequence of the Mock-up Ignition Test Method testing was:

Cycle	Test Point							
1	4	3	1	7	8	6	2	5
2	8	2	5	3	6	4	1	7
3	7	8	4	3	6	1	2	5
4	5	4	7	8	2	1	3	6
5	7	4	2	1	6	5	8	3
6	2	4	1	7	5	6	8	3
7	1	2	6	3	7	4	8	5
8	1	4	6	3	5	2	7	8

where the test points were:

Test Point	Cigarette	Fabric
1	Conventional	Duck #4
2	Conventional	Duck #6
3	Conventional	Duck #10
4	Conventional	Ivory
5	Banded	Duck #4
6	Banded	Duck #6
7	Banded	Duck #10
8	Banded	Ivory

G. Statistical Evaluation Methodology

The data obtained from these experiments were analyzed to determine whether the ignition propensities of the experimental cigarettes had changed during storage, the similarity of the new mock-ups to those used in 1993, and the degree of difference between the conventional cigarettes and those with the banded paper. The statistical analysis consisted of two steps:

1. selection of an appropriate set of statistical methods for estimating and comparing the measurements of relative ignition propensity of different types of cigarettes under different conditions as laid out in the series of experiments; and

2. analysis of the data for each set of test conditions individually, along with the comparisons of ignition propensities obtained under different test conditions.

The analysis of the data obtained under each individual test condition is relatively easy to interpret because it is given directly in terms of ignition propensity. Having this information on hand aids understanding of the somewhat less easily interpreted comparisons of different test conditions, which are differences of ignition propensities. The individual results also provide additional background information that is lost in the comparisons. The comparisons of the various test conditions, however, directly answer the main questions of interest.

Since the response variables (*i.e.*, ignition or non-ignition, full-length burning or not) observed in each of the individual experiments addressed here are binary, use of a binomial-distribution-based model for the data is appropriate. The primary assumptions are (a) that the binary outcome for each measurement from each potentially different population occurs with a particular fixed probability, p_i, and (b) that the outcome of each measurement is independent of the outcomes of all of the other measurements. Observations that meet these assumptions are said to be "independent and identically distributed."

The typical confidence interval used to estimate binomial proportions, in this case relative ignition propensities, is based on the normal distribution and has lower and upper endpoints defined respectively by[14]

$$p_L = \frac{(2n\hat{p} + z_{\alpha/2}^2 - 1) - z_{\alpha/2}\sqrt{z_{\alpha/2}^2 - (2 + 1/n) + 4\hat{p}(n(1-\hat{p}) + 1)}}{2(n + z_{\alpha/2}^2)}$$

and

$$p_U = \frac{(2n\hat{p} + z_{\alpha/2}^2 + 1) + z_{\alpha/2}\sqrt{z_{\alpha/2}^2 + (2 - 1/n) + 4\hat{p}(n(1-\hat{p}) - 1)}}{2(n + z_{\alpha/2}^2)}$$

where n is the number of mock-up or extinction tests done under a particular set of conditions, $\hat{p}$ is the proportion of tests in which an ignition or a full-length burn occurred for the Mock-up or Extinction Tests respectively, and $z_{\alpha/2}$ is the upper-tailed critical value from a standard normal distribution (*i.e.*, 1.96 for a confidence level of 95 % or $\alpha = 0.05$).

The typical confidence interval used to compare binomial probabilities from different populations, in this case relative ignition propensities of different cigarettes under different test conditions, is also based on the normal distribution.[14] It has lower and upper endpoints defined respectively by

$$d_L = (\hat{p}_1 - \hat{p}_2) - z_{\alpha/2}\sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}} - \frac{1}{2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)$$

and

$$d_U = (\hat{p}_1 - \hat{p}_2) + z_{\alpha/2}\sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}} + \frac{1}{2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)$$

[14] Fleiss, J.L., *Statistical Methods for Rates and Proportions*, John Wiley and Sons, New York, 1981.

where n_i is the number of mock-up or extinction tests done under a particular set of conditions and $\hat{p}_i$ is the proportion of tests in which an ignition or a full-length burn occurred for the mock-up or extinction tests respectively.

Determination of whether or not an observed relative ignition propensity or a difference in the relative ignition propensities for different pairs of test conditions significantly differs from a hypothesized value with these confidence intervals simply requires checking to see if the hypothesized value falls inside or outside the interval. If the hypothesized value is in the interval then the hypothesis would not be rejected. If the hypothesized value is not in the interval then the hypothesis would be rejected.

The advantages of these confidence intervals include ease of computation and familiarity. However, they depend on the central limit theorem, which states that the distribution of $\hat{p}$ will be approximately normal if the sample size is large. How large a sample size is required for the approximation to work well depends on the actual underlying relative ignition propensities. When either of the relative ignition propensities in question is near zero or one, very large sample sizes are required for the normal approximation to describe the behavior of the estimated ignition propensities adequately. Based on the data presented in the next section, the normal approximation would not work well for some of the comparisons of interest in this report.

As a result, different methods for estimation and comparison of the relative ignition propensities that do not depend on the applicability of the central limit theorem, but are more computationally intensive as a consequence, are used throughout this report. In the alternative procedures used here, confidence intervals are constructed numerically using the binomial distribution directly. The methods of Blyth and Still[15] are used for the estimation of individual ignition propensities and the methods of Coe and Tamhane[16] are used for the comparison of different ignition propensities. While requiring special software using complex algorithms, these methods provide approximate confidence intervals that are guaranteed to attain their stated confidence levels regardless of the sample sizes and true ignition propensities. In addition these methods provide intervals that will be shorter than most other methods for obtaining well-behaved, approximate confidence intervals for binomial probabilities or differences of binomial probabilities.

As for the normal-distribution intervals, for any particular comparison being made with these alternative confidence intervals statistical significance is determined by noting whether or not the confidence intervals contain a hypothesized value. For example, for the difference of two relative ignition propensities, where the natural hypothesized value is zero, the statistical significance of the difference between the ignition propensities is determined by the intervals inclusion or exclusion of zero. If the interval includes the value zero then the two ignition propensities cannot be concluded to be significantly different from one another, while if the interval does not include the value zero the appropriate conclusion is that the ignition

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[15] Blyth, C.R., and Still, H.A., "Binomial Confidence Intervals," *Journal of the American Statistical Association*, Vol. 78, March 1983, pp 108-116.

[16] Coe, P.R., and Tamhane, A.C., "Small Sample Confidence Intervals for the Difference, Ratio and Odds Ratio of Two Success Probabilities," *Communications in Statistics, Part B -- Simulation and Computation*, Vol. 22, 1993, pp 925-938.

propensities are different. The situation for the individual confidence intervals is analogous except that there is no natural, general hypothesis of interest.

IV. RESULTS AND STATISTICAL ANALYSIS OF COMPARATIVE DATA PAIRS

A. Relative Ignition Strengths of Cigarettes 529 and 531 over Time

Table 1 shows the current data on the two experimental cigarettes and the corresponding data from the 1993 ILE of the Cigarette Extinction Method. Specifically, the NIST single-laboratory data from the ILE are included in the table.

Table 1. Relative Ignition Strengths of Cigarettes 529 and 531
(number of full-length burns/number of trials)

	1993			2000		
Cigarette	**3 Layers**	**10 Layers**	**15 Layers**	**3 Layers**	**10 Layers**	**15 Layers**
529	11/16	0/16	0/16	9/24	0/24	
531	16/16	15/16	14/16		22/24	19/24

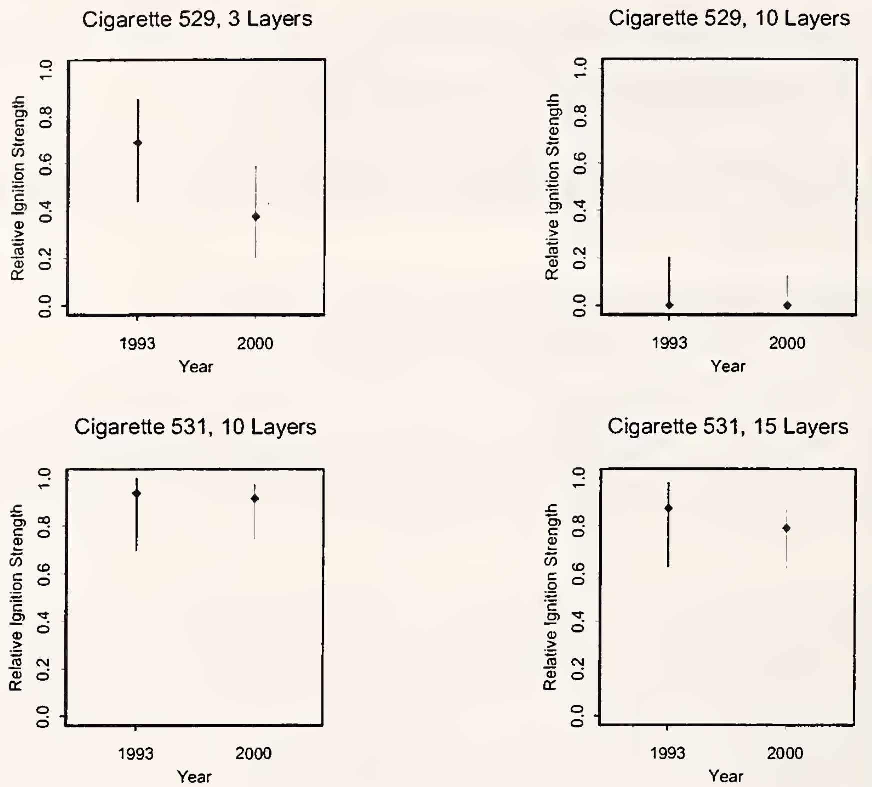
Since the Cigarette Extinction Method test procedure, the laboratory conditions, and the substrate material were the same as in the 1993 tests, and since the analysis of the 1993 ILE showed little if any dependence on the test operator, any changes observed in the relative ignition propensities of the cigarettes are attributed to the cigarettes themselves. The 95 % confidence intervals for the ignition propensity of each cigarette as measured at NIST in 1993 and in 2000 are shown in Figure 1. The large degree of overlap between the pairs of confidence intervals indicates that there is no evidence of any change in relative ignition propensity of the two laboratory cigarettes used in this comparison.

Table 2 lists approximate 95 % confidence intervals for the differences in relative ignition propensities for these two cigarettes. The fact that the confidence intervals listed in Table 2 all contain the value zero confirms the conclusion of no statistical change in the ignition propensities of these laboratory cigarettes.

Table 2. 95% Confidence Intervals for the Difference in Relative Ignition Strengths (RIS) for Cigarettes 529 and 531 over Time (RIS_{2000} - RIS_{1993})

	RIS_{2000} - RIS_{1993}		
Cigarette	**3 Layers**	**10 Layers**	**15 Layers**
529	-0.56 to 0.00	-0.19 to 0.12	
531		-0.18 to 0.19	-0.30 to 0.19

Figure 1. 95% Confidence Intervals for the Relative Ignition Strengths (RIS) for Cigarettes 529 and 531 over Time



B. Similarity of New Mock-up Substrates to 1993 ILE Substrates

Table 3 shows the current data on the two experimental cigarettes with the current fabric/foam substrates, compared with the corresponding data from the NIST participation in the 1993 ILE of the Mock-up Ignition Method.

Table 3. Similarity of New Mock-up Substrates to ILE Substrates
(number of ignitions/number of trials)

	1993			2000		
Cigarette	**Duck 10**	**Duck 6**	**Duck 4**	**Duck 10**	**Duck 6**	**Duck 4**
529	18/48	6/48	0/48	4/24	0/24	
531	47/48	48/48	0/48		23/24	0/24

Since the Mock-up Ignition Method test procedure and the operational variables were the same as for the 1993 testing and since the relative ignition propensities of the cigarettes had been shown not to have changed significantly, any differences between the 1993 and 2000 test data can be attributed to changes in the susceptibility of the substrates to cigarette ignition. Figure 2

shows the 95 % confidence intervals for each substrate at each pair of times. Again, the intervals overlap substantially, indicating that there is no evidence of difference in the ignition susceptibility of the corresponding substrates. This is confirmed by all the approximate 95 % confidence intervals in Table 4 containing the value zero.

Figure 2. 95 % Confidence Intervals for the Relative Ignition Strengths (RIS) of Cigarettes 529 and 531 on Different Mock-up Test Substrates over Time

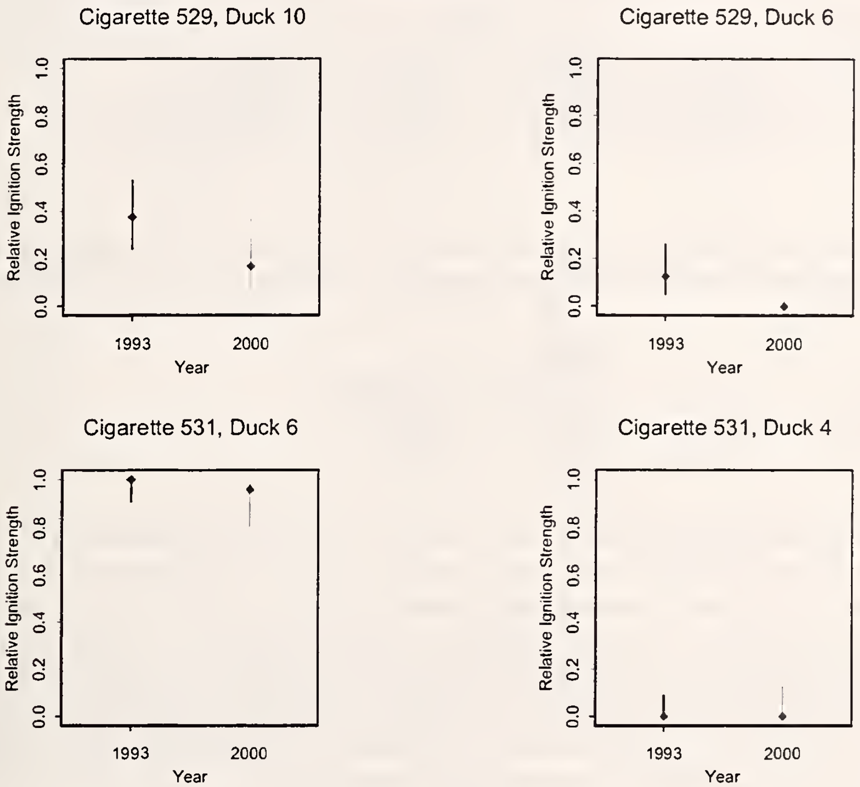


Table 4. 95 % Confidence Intervals for the Relative Ignition Strengths (RIS) of Cigarettes 529 and 531 on Different Mock-up Test Substrates (RIS_{2000} - RIS_{1993})

	RIS_{2000} - RIS_{1993}		
Cigarette	**Duck 10**	**Duck 6**	**Duck 4**
529	-0.38 to 0.02	-0.23 to 0.02	
531		-0.20 to 0.02	-0.06 to 0.14

C. Relative Ignition Propensities of the Conventional and Banded Cigarettes

Having established the properties of the substrates to be used in the tests of the conventional and banded cigarettes, the next step in the analysis was to compare these two cigarettes to see if they differ in relative ignition propensity. Tables 5 and 6 show the test results.

Table 5. Ignition Propensities of Conventional and Banded Cigarettes Measured Using the Mock-up Ignition Method (number of ignitions/number of trials)

	2000			
Cigarette	**Duck 10**	**Duck 6**	**Duck 4**	**Ivory Cot.**
Conventional	32/32	32/32	6/32	32/32
Banded	12/32	16/32	1/32	19/32

Table 6. Ignition Strengths of Conventional and Banded Cigarettes Measured Using the Cigarette Extinction Method (number of full-length burns/number of trials)

	2000		
Cigarette	**3 Layers**	**10 Layers**	**15 Layers**
Conventional	24/24	24/24	24/24
Banded	9/24	2/24	3/24

The comparison using the Mock-up Ignition Test is shown in Figure 3 and Table 7. The 95 % confidence intervals for the ignition propensities of the two cigarettes do not overlap for three of the substrates, indicating that the conventional and banded cigarettes do differ significantly in terms of relative ignition propensity on those substrates. The conventional cigarette has a high ignition propensity on the duck #6, duck #10 and ivory cotton substrates. The banded cigarette has a lower ignition propensity across these three substrates. On the most difficult substrate to ignite, duck #4, the confidence intervals do overlap substantially. This indicates that both the conventional and banded cigarettes have similarly low relative ignition propensities on this substrate. The 95 % confidence intervals for the difference in relative ignition propensity confirm these results in that each of the confidence intervals for the duck #10, duck #6 and ivory substrates has an upper confidence bound lying below zero. This indicates that all plausible values for the relative ignition propensity of the banded cigarettes are less than the plausible values of the relative ignition propensity of the conventional cigarettes. For duck #4 the confidence interval for the difference in relative ignition propensities just includes the value zero, indicating that the two cigarettes have a small range of plausible values for their ignition propensities in common.

The relative ignition propensities measured for the ivory cotton fabric substrate are not distinguishable from the values measured for the substrates containing cotton ducks #6 and #10. While the areal density of the ivory cotton fabric is in the range that industry data indicated could show reversals (relative to the cotton duck substrates) in the ranking of cigarette ignition propensity, no such reversal was found for this fabric.

Figure 3. 95 % Confidence Intervals for the Relative Ignition Strengths (RIS) of Conventional and Banded Cigarettes on Different Mock-up Test Substrates

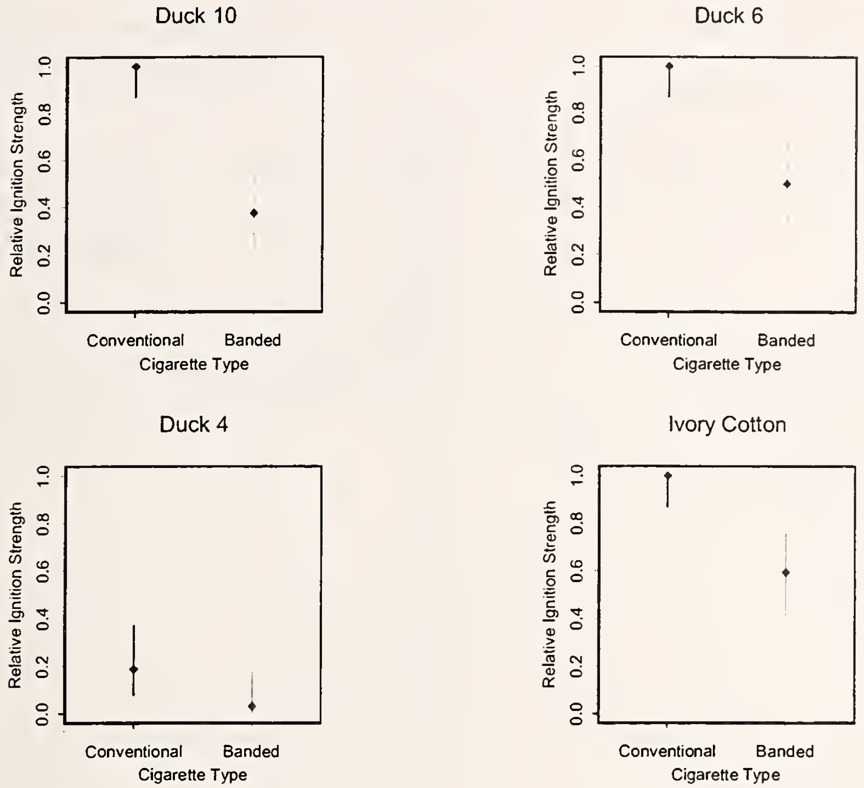


Table 7. 95 % Confidence Intervals for the Difference in Relative Ignition Strengths of Conventional and Banded Cigarettes on Different Mock-up Test Substrates ($RIS_{Banded} - RIS_{Conventional}$)

$RIS_{Banded} - RIS_{Conventional}$			
Duck 10	**Duck 6**	**Duck 4**	**Ivory Cot.**
-0.77 to –0.41	-0.66 to -0.31	-0.31 to 0.00	-0.57 to -0.23

The results of the comparison of the standard and banded cigarettes using the Extinction Test are shown in Figure 4 and Table 8. The interpretation of the plots in Figure 4 and the confidence intervals in Table 8 is similar to those for the Mock-up Ignition Test. In the case of the Extinction Test, however, the modified cigarette showed a significantly lower relative ignition propensity than the conventional cigarette on *all* substrates.

Figure 4. 95 % Confidence Intervals for the Relative Ignition Strengths (RIS) of Conventional and Banded Cigarettes on Different Extinction Test Substrates

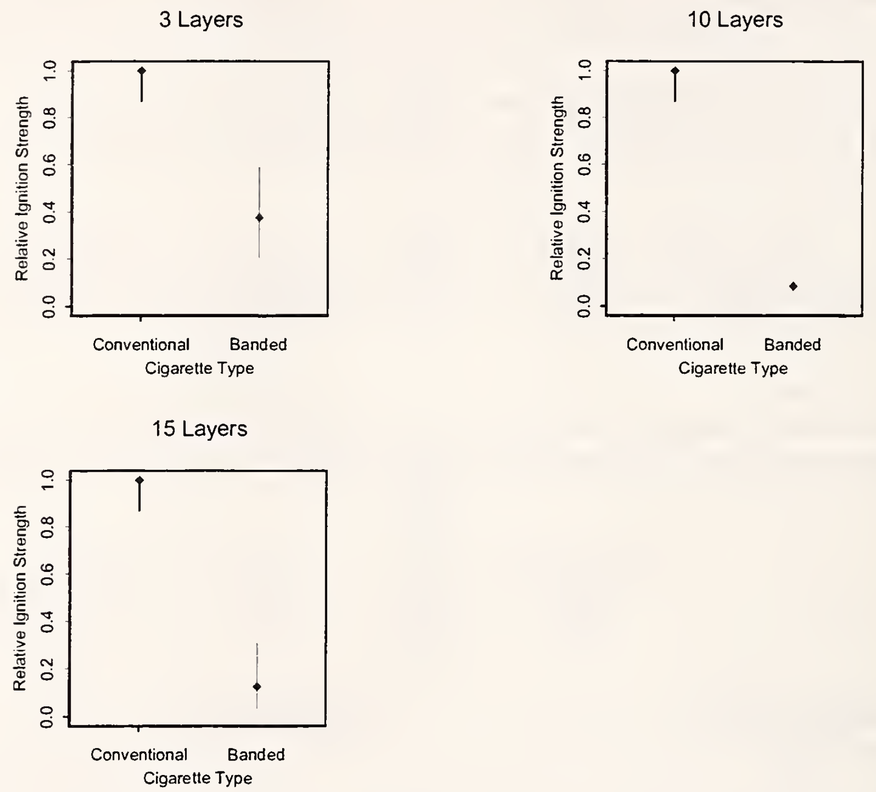


Table 8. 95 % Confidence Intervals for the Difference in Relative Ignition Strengths of Conventional and Banded Cigarettes on Different Extinction Test Substrates ($RIS_{Banded} - RIS_{Conventional}$)

$RIS_{Banded} - RIS_{Conventional}$		
3 Layers	**10 Layers**	**15 Layers**
-0.79 to –0.38	-0.98 to -0.69	-0.97 to -0.64

V. DISCUSSION

The above analysis shows that the banded cigarettes produced significantly fewer failures in both test methods than did their conventional counterparts. Table 9 puts these results in context with the data from reference 9. The 14 best-selling commercial cigarettes in 1993 ignited the mock-ups or burned their full length on filter paper in virtually every test. [The results for one of these cigarettes are shown in the first row.] Cigarettes A through F are other 1993 commercial cigarettes that were expected, based on values of their physical properties, to have reduced

ignition propensities. The five numbered cigarettes are those experimental cigarettes used in the ILE of the two test methods.

Table 9. Percent Ignitions or Full Length Burns on Test Method Substrates [Prior data from reference 9]

SUBSTRATE → CIGARETTE ↓	3 layers	Duck #10	10 layers	Duck #6	15 layers	Duck #4
1993 Commercial	100	100	100	100	100	100
B	100	100	100	92	94	73
503	100	100	100	100	100	53
Conventional	100	100	100	100	100	19
501	100	100	100	100	100	11
D	100	100	94	73	88	46
E	100	100	100	96	94	0
531	99	98	94	95	88	0
A	100	100	94	92	38	4
F	100	100	100	79	19	0
529	57	30	6	8	2	0
Banded	39	37	8	50	12	3
530	6	3	0	0	0	0

Cigarettes 531 and 529 differ in the air permeability of the wrapping paper. The same is true of the conventional and banded cigarettes, although the permeability difference is only in the banded regions. There is a similarity in performance between the 531 and the conventional cigarette, with nominally 100 % failures on five of the six substrates. The 529 and banded cigarette show similar and significant improvements on those five substrates, as well as large differences from the 1993 best-selling cigarettes. For the #4 cotton duck substrate, the most difficult to ignite, the conventional cigarette caused relatively few ignitions, leaving no room for the banded version to show improvement.

VI. CONCLUSION

As requested by the Federal Trade Commission staff, NIST has measured the ignition propensity of a test market cigarette made with slower burning paper relative to the performance of the unmodified product. Analysis of the test data shows that the banded cigarette has a lower relative ignition propensity than its conventional counterpart.

APPENDIX A. Request Letter of May 15, 2000, from the Federal Trade Commission to the National Institute of Standards and Technology

UNITED STATES OF AMERICA
FEDERAL TRADE COMMISSION
WASHINGTON, D.C. 20580

Bureau of Consumer Protection

May 15, 2000

Dr. Jack E. Snell
Director
Building and Fire Research Laboratory
Mail Stop 8600
National Institute of Standards and Technology
100 Bureau Drive
Gaithersburg, MD 20899-8600

Dear Dr. Snell:

It is my understanding that the National Institute of Standards and Technology ("NIST") is able to conduct tests to determine the relative likelihood of ignition of different types of cigarettes, and would be willing to conduct such tests upon request by the Federal Trade Commission. Philip Morris, Inc. recently announced publicly its plans to test market a cigarette made with a slower burning paper that would reduce the risk that a dropped or discarded cigarette will start a fire.[1] It would greatly assist the Commission in its responsibilities over tobacco products if NIST would conduct tests to determine whether and to what extent this cigarette does reduce the risk of ignition. Thus, I am requesting that NIST perform such tests as needed to evaluate this cigarette.

Thank you very much for your assistance. If you have any questions, please call Rosemary Rosso at (202) 326-2174.

Sincerely,

Jodie Bernstein

Joan Z. Bernstein
Director
Bureau of Consumer Protection

cc: Dr. Richard G. Gann

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[1] See "Philip Morris Plans Slow Burn Paper," www.nytimes.com/aponline/f/AP-Slow-Burn.html (Jan. 11, 2000).

APPENDIX B. Reply Letter of May 19, 2000, from the National Institute of Standards and Technology to the Federal Trade Commission.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899-

May 19, 2000

Ms. Joan Z. Bernstein
Director, Bureau of Consumer Protection
Federal Trade Commission
Washington, D.C. 20580

Dear Ms. Bernstein:

Thank you for your letter requesting that the National Institute of Standards and Technology (NIST) use its expertise to determine the relative likelihood of ignition of soft furnishings by the new cigarettes of Philip Morris, Inc. While NIST does not routinely perform product tests, we recognize the important role of the Federal Trade Commission in assuring the public of the veracity of product claims and the high potential for less fire-prone cigarettes to reduce fire deaths and injuries. We thus agree to measure the ignition propensity of these test cigarettes relative to the performance of the unmodified product. Note that this is not an absolute measure of ignition probability in real circumstances, but is a strong indicator as to whether a reduction in cigarette-initiated fires might be expected.

We should be able to complete our work and transmit a report to you within 5 months. After no more than a short delay, we would expect the report to become public.

Dr. Richard Gann [phone: (301) 975-6866; rggann@nist.gov] will be our point of contact to work with Ms. Rosso on this matter.

Sincerely,

Jack E. Snell, Director
Building and Fire Research Laboratory

cc: Richard Gann
Raymond Kammer
Michael Rubin
Matthew Heyman
Rosemary Rosso

NIST

APPENDIX C. MOCK-UP IGNITION METHOD

This test method measures the probability that a lit cigarette, placed on one of three standardized upholstery mock-ups, will ignite the mock-up to smoldering combustion. The mock-ups consist of a sheet of fabric over a block of flexible polyurethane foam. One substrate has a sheet of plastic film between the fabric and the foam to increase the overall thermal mass. A number of replicate tests (composing a trial) are performed to obtain the relative probability that the cigarette will ignite the substrate. Four of these apparatus were used concurrently.

1. Apparatus and Equipment

   An environmental conditioning room provided an area adequate for conditioning both cigarettes and filter paper specimens. This room was maintained at a relative humidity of 55 % ± 5 % and a temperature of 23 °C ± 3 °C and was continuously monitored.

   A test chamber of the design photographed in Figures C-1 and C-2 was used for testing the cigarette/substrate combinations.

   A square brass rim, shown in Figure C-2 was used to hold the fabric (and film) flat against each other and the foam. The outside dimension of the rim was 200 mm ± 2 mm. The inner dimension was 150 mm ± 2 mm. The thickness was 3 mm ± 1 mm. The rim surface was flat and smooth.

   A cylindrical holder supported the cigarette in the test chamber prior to placement onto the filter paper substrate. The cylinder was of a length and diameter to support the cigarette in a vertical position, coal side up, without damaging the cigarette. The base plate for the cylinder was just under 50 mm in diameter, and the holder weighed less than 70 g.

   A butane gas lighter capable of producing a stable luminous flame for approximately 15 mm in length was used for lighting the cigarette. The cigarette was supported in a horizontal position, with an airflow through the cigarette of 15 mL/s - 20 mL/s. The draw time through the lit cigarette was sufficient to establish a coal equal to or less than 5 mm in length. Filtering media were used downstream of the cigarette to remove smoke and condensable combustion gases in order to prevent contamination of the downstream components.

   A chemical or canopy hood removed combustion products from the test room. Airflow through the hood was sufficient to remove cigarette and substrate combustion products while not being high enough to influence the combustion processes in the test chamber(s).

   Following a test, the cigarette and substrate materials were completely extinguished with a small stream of water.

2. Calibration and Standardization

Calibrations of equipment were carried out at regular intervals and at any time when equipment or test conditions indicate that evaluation and re-calibration were necessary.

The ignition test chambers were checked before use to insure that the front door seals properly and that air movement in the test area does not introduce transient air movement in the test chambers. Door seals were checked visually to ensure that they closed flush against the chamber's side wall and the latching device secured the door tightly. All construction seams were inspected to ensure they were airtight, with no cracks visible on any surface of the test chamber.

The stability of the air inside each test chamber was determined daily by placing a lit cigarette in the test position on one or more layers of filter paper, then closing the chamber door. Smoke being emitted by the cigarette rose vertically and showed no turbulence within 150 mm above the lit end of the cigarette.

The humidity and temperature sensors used to record environmental conditions in the conditioning room or the chamber and test room were checked for accuracy daily.

The air draw apparatus used for igniting cigarettes was calibrated at the beginning and end of this project.

3. Test Specimens and Standard Substrate Assemblies

Cigarette test specimens were protected from physical or environmental damage while in handling and storage. Clean plastic gloves were worn at all times to minimize contamination of the cigarette test specimens and filter paper substrates, which are sensitive to contamination. If the specimens were to be stored for more than one week, they were placed in a freezer reserved for the sole protection of cigarette specimens.

Prior to testing, cigarette test specimens were marked on their paper seam 5 mm and 15 mm from the tobacco end with a #2 graphite pencil. These marks are used to establish a uniform burn and the start of the coal respectively.

The substrate materials were as follows:

The open-cell, non-fire-retarded flexible polyurethane foam had been cut into blocks 200 mm ± 5 mm square and 50 mm ± 2 mm thick. The foam density was 32 kg/m^2 ± 3 kg/m^2 and the air permeability was 1.9×10^{-3} m^3/s ± 0.1×10^{-3} m^3/s.

Three standard test fabrics were used, having the following nominal properties:

100 % Cotton Duck	Areal Density (kg/m^2)	Yarn Count (per inch)	Yarn Plies	Air Permeability ($10^{-3}\ m^3s^{-1}m^{-2}$)
#4	0.83	31 x 24	4 x 4	5.1 to10.2
#6	0.72	36 x 26	3 x 3	5.1 to10.2
#10	0.50	40 x 28	2 x 2	10.2 to20.4

A fourth 100 % cotton fabric had an areal density of 0.36 kg/m^2.

The polyethylene film used with the #4 cotton duck substrates had a thickness of 0.15 mm ± 0.007 mm and an areal density of 0.012 kg/m^2 ± 0.005 kg/m^2.

The substrates were formed by placing the fabric (and film) on the foam, then placing the metal rim on top to ensure good contact between the layers.

4. Conditioning

The cigarettes were conditioned at a relative humidity of 55 % ± 5 % and a temperature of 23 °C ± 3 °C for at least 24 hours prior to ignition testing. The cigarettes were stored vertically, filter end up, in a clean 250 mL glass beaker, with a maximum of 20 cigarettes per beaker to enable free air access to the specimens.

The substrate materials were also conditioned at a relative humidity of 55 % ± 5 % and a temperature of 23 °C ± 3 °C for at least one week prior to ignition testing.

5. Procedure

Turn on the exhaust system designated for removal of test combustion products 30 min prior to beginning testing.

Cover the chimney on the test chamber.

Select the substrate materials for the scheduled test. Place the assembly in the test chamber at the geometric center of its bottom and place the metal test rim on top.

Place the cigarette holder on the center of the fabric.

Without delay, remove a cigarette from the conditioned space. Insert the unmarked end of the cigarette into the cigarette ignition system and hold it in a horizontal position. Turn on the air draw, verifying that the air flow is 15 mL/s to 20 mL/s. Hold the ignition flame or hot wire coil to the marked end of the cigarette for as long as is necessary to achieve uniform ignition without passing the 5 mm mark.

Holding the cigarette vertically, coal end up and under a 600 mL beaker, transport the cigarette to the test chamber.

Place the lit cigarette, still vertical, in the cigarette holder.

Simultaneously close the door and remove the chimney cover.

If the cigarette should self-extinguish while in the cigarette holder, terminate the test and record the results as a self-extinguishment and note that this occurred in the holder.

When the cigarette has burned to the 15 mm mark, simultaneously replace the chimney cover and open the chamber door, gently remove the cigarette from the holder, and move the holder to the front corner of the test chamber.

Gently lay the cigarette with the ash still attached onto the top of the fabric so that the coal end is located at the geometric center of the surface and the cigarette axis is diagonal to the fabric warp. The cigarette paper seam is turned up. Do not drop the cigarette onto the fabric and do not press the coal into the fabric. If the ash falls off during any part of the transport or positioning process, terminate the test and begin again; do not count the attempt.

Without delay, simultaneously remove the chimney cover and gently close the door.

Observe the burning cigarette. The smoke plume near the cigarette must remain undisturbed. If it does not, this observation shall be noted on the test sheet.

Record the following results:

(1) Ignition: the char mark on the fabric propagates at least 10 mm from the edge of the cigarette;
(2) Non-ignition: the tobacco column burns to the end without causing an ignition; or
(3) Self-extinguishment: the coal goes out before the tobacco column is consumed.

Extinguish the cigarette and the substrate materials using a water bottle.

Open the test chamber door to allow air to circulate throughout its volume. After the chamber has cleared, prepare for the next test.

Repeat the test with each cigarette the requisite number of times per trial. Calculate the percentage of tests in which the cigarettes burned their full length.

6. Test Report

Report the following information for each test:

Name of person performing the test
The temperature and relative humidity in the laboratory
Date of each test
Cigarette identification
The fabric type and sample number
The sample number for the foam block and plastic film
The outcome of the test

For each trial, report the percentage of tests in which the cigarettes ignited the substrates.

Figure C-1. Photograph of Test Chamber and Cigarette on Mock-up Assembly

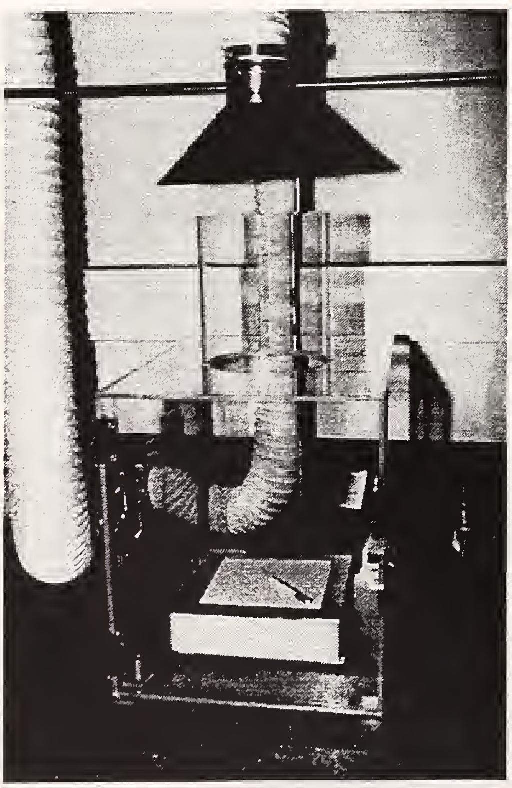
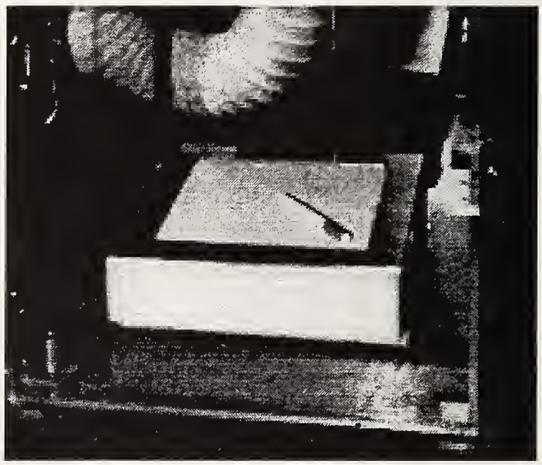


Figure C-2. Close-up of Cigarette on Mock-up Assembly with Square Frame in Place



APPENDIX D. CIGARETTE EXTINCTION METHOD

This test method measures the probability that a cigarette, placed on a substrate, will generate insufficient heat to maintain burning of the tobacco column. Each test consists of placing a lit cigarette on the horizontal surface consisting of a set number of layers of filter paper. Observation is made of whether or not the cigarette continues to burn the full length of the tobacco column. A number of replicate tests (composing a trial) are performed to obtain the relative probability that the cigarette will be extinguished by heat abstraction by the substrate. Four of these apparatus were used concurrently.

7. Apparatus and Equipment

An environmental conditioning room provided an area adequate for conditioning both cigarettes and filter paper specimens. This room was maintained at a relative humidity of 55 % ± 5 % and a temperature of 23 °C ± 3 °C and was continuously monitored.

A test chamber of the design photographed in Figures D-1 and D-2 was used for testing the cigarette/substrate combinations.

A cylindrical support for the layers of filter paper, shown in Figure D-2, was of PMMA and dimensioned as follows: outer diameter of 165 ± 1 mm, inner diameter of 127 mm ± 1 mm, and a height of 50 mm ± 1 mm. A recess in the top, 8 ± 1 mm deep, expanded the inner diameter to 152 mm ± 1 mm. Three or four legs raised the bottom of the holder approximately 20 mm above the chamber floor.

A circular brass or similar metal rim, shown in Figure D-2 was used to hold the sheets of filter paper flat against each other. The outside diameter of the rim was 150 mm ± 2 mm. The inner diameter was 130 mm ± 2 mm. The thickness was 3 mm ± 1 mm. The rim surface was flat and smooth. A pair of parallel metal pins, each approximately 1 mm in diameter and 8.1 mm ± 0.05 mm apart, protruded approximately 20 mm toward the center of the rim, spaced to keep the filter end of a conventional 25 mm circumference cigarette from rolling, but without pressuring the filter. When cigarettes of significantly different diameter were tested, other pairs of pins, appropriately spaced, were inserted into the rim.

A cylindrical holder supported the cigarette in the test chamber prior to placement onto the filter paper substrate. The cylinder was of a length and diameter to support the cigarette in a vertical position, coal side up, without damaging the cigarette. The base plate for the cylinder was just under 50 mm in diameter, and the holder weighed less than 70 g.

A butane gas lighter capable of producing a stable luminous flame for approximately 15 mm in length was used for lighting the cigarette. The cigarette was supported in a horizontal position, with an air flow through the cigarette of 15 mL/s to 20 mL/s. The draw time through the lit cigarette was sufficient to establish a coal equal to or less than 5 mm in length. Filtering media were used downstream of the cigarette to remove smoke

and condensable combustion gases in order to prevent contamination of the downstream components.

A chemical or canopy hood removed combustion products from the test room. Airflow through the hood was sufficient to remove cigarette and substrate combustion products while not being high enough to influence the combustion processes in the test chamber(s).

Following a test, the cigarette and sheets of filter paper were completely extinguished.

8. Calibration and Standardization

Calibrations of equipment were carried out at regular intervals and at any time when equipment or test conditions indicated that evaluation and re-calibration were necessary.

The ignition test chambers were checked before use to insure that the front door seals properly and that air movement in the test area does not introduce transient air movement in the test chambers. Door seals were checked visually to ensure that they closed flush against the chamber's side wall and the latching device secured the door tightly. All construction seams were inspected to ensure they were airtight, with no cracks visible on any surface of the test chamber.

The stability of the air inside each test chamber was determined daily by placing a lit cigarette in the test position on one or more layers of filter paper, then closing the chamber door. Smoke being emitted by the cigarette rose vertically and showed no turbulence within 150 mm above the lit end of the cigarette.

The humidity and temperature sensors used to record environmental conditions in the conditioning room or the chamber and test room were checked for accuracy daily.

The air draw apparatus used for igniting cigarettes was calibrated at the beginning and end of this project.

9. Test Specimens and Standard Substrate Assemblies

Cigarette test specimens were protected from physical or environmental damage while in handling and storage. Clean plastic gloves were worn at all times to minimize contamination of the cigarette test specimens and filter paper substrates, which are sensitive to contamination. If the specimens were to be stored for more than one week, they were placed in a freezer reserved for the sole protection of cigarette specimens.

Prior to testing, cigarette test specimens were marked on their paper seam 5 mm and 15 mm from the tobacco end with a #2 graphite pencil. These marks are used to establish a uniform burn and the start of the coal respectively.

The filter paper substrates consisted of 150 mm diameter circles of Whatman #2 filter paper. They were formed by placing multiple layers of filter paper into the holder assembly, then placing the metal rim on top to ensure good contact between the layers.

10. Conditioning

The cigarettes were conditioned at a relative humidity of 55 % ± 5 % and a temperature of 23 °C ± 3 °C for at least 24 hours prior to ignition testing. The cigarettes were stored vertically, filter end up, in a clean 250 mL polyethylene or glass beaker, with a maximum of 20 cigarettes per beaker to enable free air access to the specimens.

Filter papers were conditioned at a relative humidity of 55 % ± 5 % and a temperature of 23 °C ± 3 °C for at least 24 hours prior to ignition testing. Individual papers were supported side-be-side in racks that held each piece vertically on edge and maintained air spaces between the individual sheets. Small fans located *ca.* 100 mm above the tops of the sheets provided gentle downward air circulation.

11. Procedure

Turn on the exhaust system designated for removal of test combustion products 30 min prior to beginning testing.

Ensure that the filter paper holder is in the test chamber at the geometric center of its bottom. Cover the chimney on the test chamber.

Select the number of layers of filter paper for the scheduled tests. Immediately before testing, place the proper number of filter papers on the filter paper holder and place the metal test rim on top. Do not use filter papers that will not lay flat.

Place the cigarette holder on the center of the filter papers.

Without delay, remove a cigarette from the conditioned space. Insert the unmarked end of the cigarette into the cigarette ignition system and hold it in a horizontal position. Turn on the air draw, verifying that the air flow is 15 mL/s to 20 mL/s. Hold the ignition flame to the marked end of the cigarette for as long as is necessary to achieve uniform ignition without passing the 5 mm mark.

Holding the cigarette vertically, coal end up and under a 600 mL beaker, transport the cigarette to the test chamber.

Place the lit cigarette, still vertical, in the cigarette holder.

Simultaneously close the door and remove the chimney cover.

If the cigarette should self-extinguish while in the cigarette holder, terminate the test and record the results as a self-extinguishment and note that this occurred in the holder.

When the cigarette has burned to the 15 mm mark, simultaneously replace the chimney cover and open the chamber door, then gently remove the cigarette from the holder, and move the holder to the front corner of the test chamber.

Gently lay the cigarette with the ash still attached onto the top of the filter papers so that the "filter" end is placed between the appropriately sized cigarette anti-roll fingers. The cigarette paper seam is turned up. Do not drop the cigarette onto the filter papers and do not press the coal into the papers. If the ash falls off during any part of the transport or positioning process, terminate the test and begin again; do not count the attempt.

Without delay, simultaneously remove the chimney cover and gently close the door.

Observe the burning cigarette. The smoke plume near the cigarette must remain undisturbed. If it does not, this observation shall be noted on the test sheet.

Record the following results:

(1) The cigarette burns the full length of the tobacco column or
(2) The burning ceases before reaching the end of the tobacco column.

Ensure that neither the cigarette nor the filter papers are still burning.

Open the test chamber door to allow air to circulate throughout its volume. After the chamber has cleared, prepare for the next test.

Repeat the test with each cigarette the requisite number of times per trial. Calculate the percentage of tests in which the cigarettes burned their full length.

12. Test Report

Report the following information for each trial:

Name of person performing the test
The temperature and relative humidity in the laboratory
Date of each test
Cigarette identification
Number of layers of filter paper per test
The percentage of tests in which the cigarettes burned their full length

Figure D-1. Photograph of Test Chamber and Filter Paper Holder

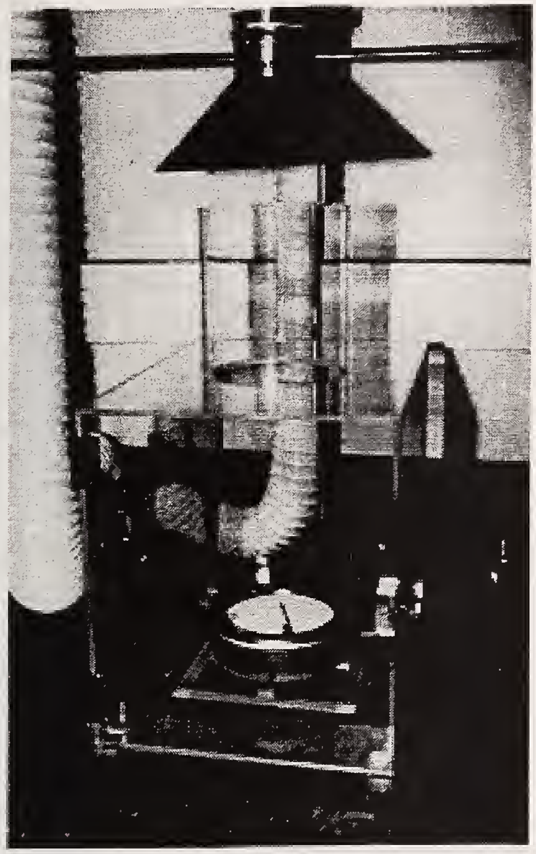
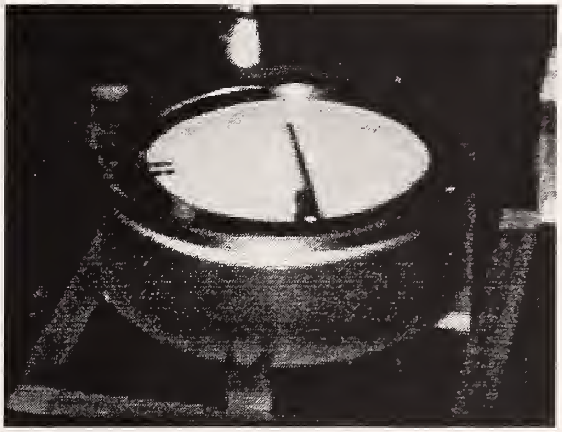


Figure D-2. Close-up of Filter Paper Holder and Metal Rim



APPENDIX E. MEASUREMENT OF CIGARETTE PAPER BANDS
(Work performed by Jiann C. Yang, NIST)

Two samples of the banded paper were obtained by removing the filters and tobacco from two cigarettes. The curled papers were straightened by placing them between two glass slides overnight. The papers were placed in a 35 mm film and negative holder and digitized using a slide scanner (Microtek ScanMaker 35t). The width of the paper band and the distance between the two adjacent bands were obtained by enhancing (histogram stretching) and analyzing the digital images using image analysis software (SigmaScanPro 4.0). Spatial calibration was obtained by scanning a Leica 2 mm micrometer mounted on a glass slide. The uncertainty associated with the calibration micrometer is ± 1 pixel (0.02 mm). For each paper sample, 10 random measurements were made along the width of the band and the distance between the two bands.

Table E-1. Measurement of Band Width and Band Separation

Cigarette paper 1				Cigarette paper 2			
Width (pixels)	Width (mm)	Separation (pixels)	Separation (mm)	Width (pixels)	Width (mm)	Separation (pixels)	Separation (mm)
272	5.79	1016	21.62	309	6.58	936	19.92
264	5.62	1024	21.79	309	6.58	938	19.96
262	5.58	1000	21.28	308	6.55	934	19.87
272	5.79	1016	21.62	311	6.62	936	19.92
270	5.75	1016	21.62	308	6.55	936	19.92
266	5.66	1012	21.53	310	6.60	942	20.04
272	5.79	1012	21.53	308	6.55	940	20.00
273	5.81	1008	21.45	309	6.58	932	19.83
262	5.58	1020	21.70	310	6.60	936	19.92
266	5.66	1004	21.36	310	6.60	938	19.96
	5.70 ± 0.09 mean ± std		21.55 ± 0.15 mean ± std		6.58 ± 0.03 mean ± std		19.93 ± 0.06 mean ± std
Calibration factor: 2 mm = 47 pixels							